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URBANA

REPORT OF INVESTIGATIONS—NO. 114

MARINE POOL, MADISON COUNTY

A New Type of Oil Reservoir in Illinois

BY

H. A. LOWENSTAM AND E. P. DUBOIS

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Topographic Mapping in Cooperation with the United States Geological Survey.
This report is a contribution of the Oil and Gas Division.

November 10, 1945

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ILLUSTRATIONS

MARINE POOL, MADISON COUNTY

A New Type of Oil Reservoir in Illinois

BY

H. A. Lowenstam and E. P. DuBois

INTRODUCTION

THIS REPORT describes the occurrence of oil in a Silurian coral reef, the first commercial occurrence of this type in Illinois. Because there is a considerable area within the State where stratigraphic traps of this sort may be found, it is believed that the description and discussion of the Marine pool is of special interest. Broad regional studies will be needed to evaluate the possibilities for additional oil occurrences of this sort.

The area concerned includes T. 4 N., R. 6 W., and portions of adjacent townships in Madison County, Illinois (fig. 1). The Marine pool proper is located in secs. 9, 10, 15, and 16 with some outlying production in secs. 3 and 8. The principal producing zone is the upper portion of the Silurian strata. The pool lies on the western side of the Illinois basin in a region where the surface of the Devonian strata dips to the southeast at a rate of about 30 feet to the mile. The geologic strata present are of Pleistocene, Pennsylvanian, Mississippian, Devonian, and Silurian age.

The object of this study is to describe the character of the oil reservoir in the Marine pool and to point out its significance in relation to future oil prospecting in Illinois.

The report is based on data available as of May 10, 1945. During the seven-month period, May through November, 16 producing wells were completed in the Marine pool making a total on December 1, 1945, of fifty-three producing wells in the pool. Cumulative production to November 1, the latest date available, was approximately 1,163,000 barrels. Data from the new wells do not change the interpretations in the report in any essential way.

DEVELOPMENT OF THE POOL

Seismograph and gravity surveys indicated the presence of the structure here designated as the Marine dome. The discovery well was the Eason and Company—Mayer No. 1, in the SE. $\frac{1}{4}$, NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, sec. 15, T. 4 N., R. 6 W., completed in July, 1943. This well, which was drilled on the southeastern flank of the structure, had an initial production of 14 barrels of oil and 3 barrels of water per day. It was abandoned almost immediately because of the low production.

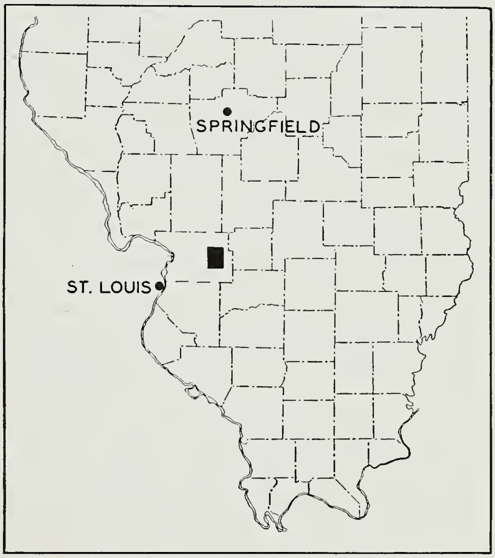


Fig. 1.—Index map showing location of the Marine area.

Development proceeded slowly, averaging about two completions a month, with a maximum of five completions in November, 1944 and in January, 1945 (fig. 2). By May 1, 1945, there were 37 producing wells in the field with a cumulative produc-

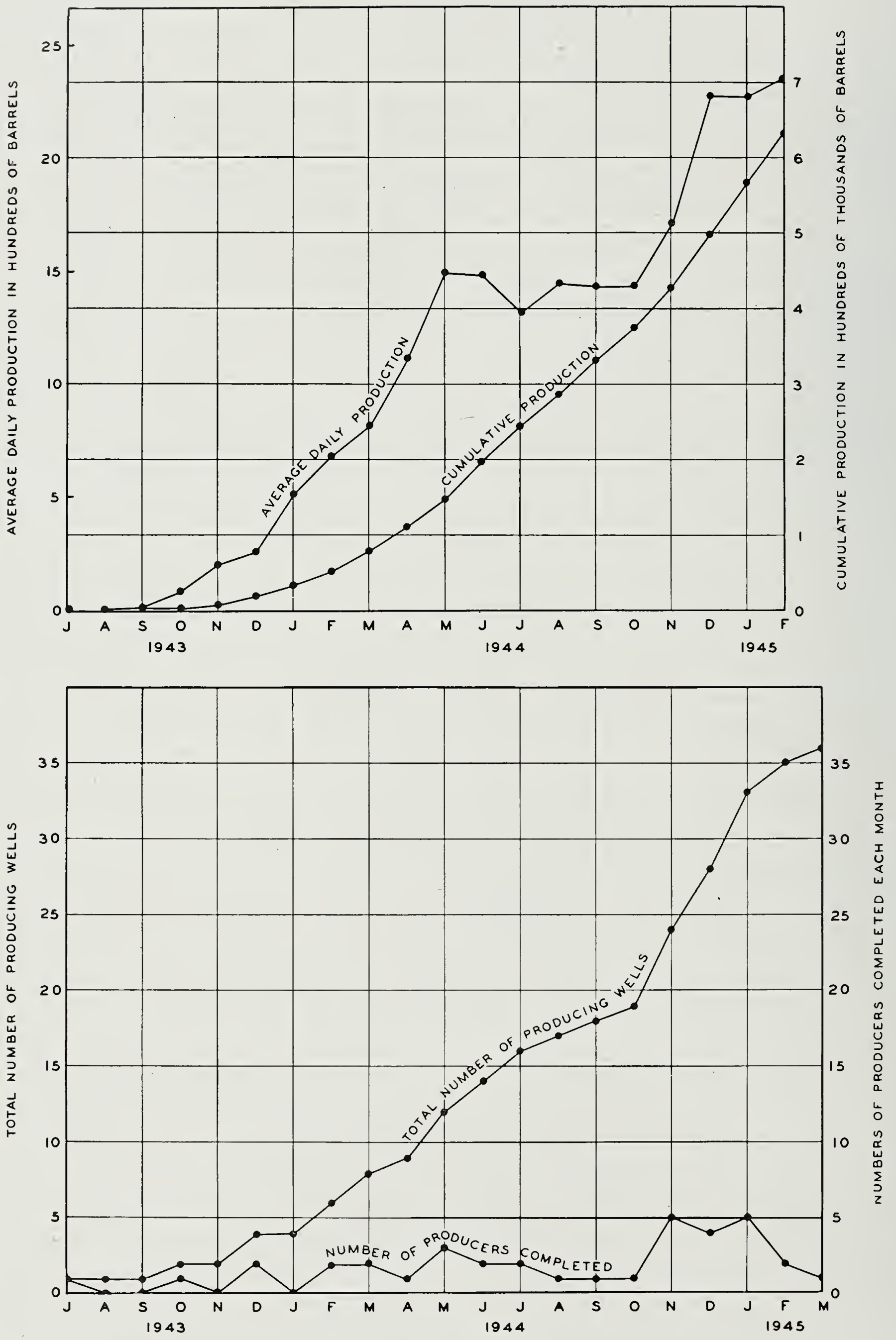


Fig. 2.—Drilling and production curves, Marine pool.

tion of more than 757,000 barrels of oil and an average daily production for the field of about 2,200 barrels.

Most of the wells were drilled by rotary tools to a depth a few feet below the top of the Devonian limestone, where casing was set and cemented. The wells were then completed with cable tools and were either shot or acidized. One, two, or occasionally three "breaks" have been reported at varying depths below the top of the Silurian. A few wells appear to be producing from fissures in the Devonian strata. Initial productions have averaged about 150 barrels per day (table 1).

STRATIGRAPHIC SUMMARY

Figure 3

The strata below the Pleistocene till or glacial drift include about 500 feet of sandstones and shales of Pennsylvanian age, and about 200 feet of sandstones, shales, and limestones of Upper Mississippian (Chester) age (fig. 3). The Golconda formation is generally the uppermost unit of the Chester series, but in a few places it has been cut through by post-Chester erosion so that the Pennsylvanian strata rest upon lower beds. The Lower Mississippian strata include about 40 feet of Ste. Genevieve limestone, 160 feet of St. Louis limestone, 120 feet of fossiliferous Salem limestone, and about 475 feet of limestones, shales, and siltstones of Osage age. The Chouteau limestone averages about 25 feet in thickness and in some wells is separated from the brown and black shales of Upper Devonian-Kinderhook age by 10 feet, more or less, of green and red shales. The dark colored shales of Upper Devonian-Kinderhook age are about 70 feet thick.

The Devonian strata are represented by an undifferentiated upper shaly and silty zone and by the Cedar Valley and Wapsipinicon limestones. The total thickness of the Devonian beds ranges from 25 to 35 feet. The underlying Silurian formations range from 430 to 570 feet in total thickness, with the thicker sections being near the reef. It is presumed that even greater thicknesses of Silurian beds exist within the

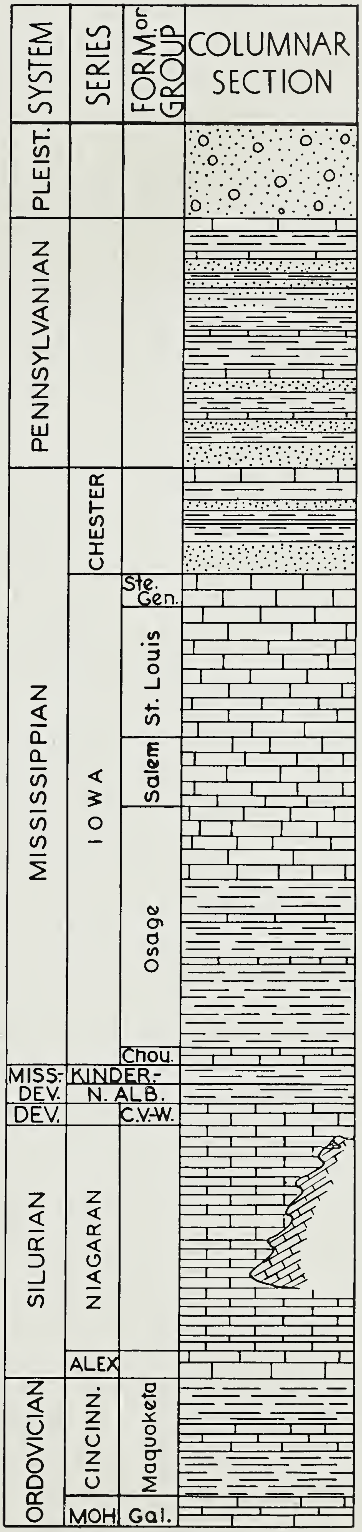


Fig. 3.—Sequence of strata in the Marine pool.

Table 1.—Well Data for Marine Pool
May 10, 1945

Company and Farm	Location	I P*	Treatment
	T. 4 N., R. 6 W. Section		
Rock Hill et al.—John Becker 1	NW SW SE 3	52 BOP+150 BW*	—
Obering—Bird 1	SE NW SE 8	45 BOP	—
Hubbard—Kolb 1	SE SW SW 9	34 BOP+300 BW (Worked over 28 BOP)	Acidized 200 gals.
Obering et al.—Becker–I.C. RR. 1	SE SW SE 9	80 BOP	—
Obering et al.—Becker–I.C. RR. 2	SE NW SE 9	58 BOP+10 BW	—
Obering—John E. Becker Comm. 1	SE SE SE 9	115 BOF (W.O. 264 BOP+10 BW)	— —
Obering, MacDowell, Lord–Becker Comm. 2	SE NE SE 9	236 BOF	—
Obering—Becker-Pence 3	NW SE SE 9	84 BOP	—
Obering—Becker–I.C. RR. 3	NW SW SE 9	877 BOF	—
Obering—Becker–Pence 4	NW NE SE 9	150 BOP	—
Obering—Grimm 1	SE SE SW 9	101 BOP	—
Obering—Grimm 2	SE NE SW 9	164 BOP	—
Ohio—E. H. Grotefendt 1	SE SE NE 9	128 BOP	—
Ohio—Grotefendt–I.C. RR. Comm. 1	SE SW NE 9	38 BOP+15 BW	—
Shell Oil—Kettler 1	SE NW SW 9	D & A (Show oil)	Acidized 750 gals.
Rock Hill O. & G.–Pence 1	SE SW SW 10	241 BOF	Acidized 250 gals.
Rock Hill O. & G.—Pence 2	SE SE SW 10	75 BOP+10 BW	—
Rock Hill and Obering—Pence 3	NW SW SW 10	224 BOP	Shot 10 qts.
Rock Hill—W. H. Pence 4	NW SE SW 10	249 BOP	Shot 30 qts.
Sinclair–Wyoming—Hess 1	930 N 330 E NW SW 10	373 BOF + 17 BW	—
Sinclair–Wyoming—Hess 2	SE SW NW 10	22 BOP + 7 BW	—
Sinclair–Wyoming—Ben Hess 2–A	290 S 1100 W SW NW 10	SWD	—
Sinclair–Wyoming—Hess 3	NW NW SW 10	45 BOP 240 BOS (OWWO)	Acidized 2000
Rock Hill Oil (Eason & Co.)–L. Mayer 1	SE NW SW 15	14 BOP + 3 BW	—
Ohio Oil—Pence 1	SE NW NW 15	27 BOP	Acidized 300 gals.
Ohio—Pence Comm. 2	NW NW NW 15	152 BOP	Acidized 200 gals.
Rock Hill—Horn 1	SE SE SW 15	D & A	—
Kacalieff—Illinois Central RR. 1	SE SE NW 16	30 BOP + 10 BW	100 gals.
Rock Hill—Mayer 2	300 S. 360 E SE SE NE 16	50 BOP + 750 BW	1000 gals.
H. P. Hubbard—Kolb 2	SE NW NW 16	150 BOP + 5BW	—
H. Hubbard—Kolb 3	SE SW NW 16	30 BOP + 2 BW	Shot 10 qts.
Rock Hill—Pence 1	SE NE NE 16	168 BOP + 103 BW	Acidized 3000 gals.
Rock Hill—Pence 1–D	710 S 125 E SE NE 16	SWD	—
Rock Hill—Pence 1–Elbring–I.C. RR. 1	SE NW NE 16	190 BOF	—
Rock Hill—Pence–Mayer 3	NW NE NE 16	350 BOP	Shot 20 qts.
Rock Hill—Pence–Mayer 4	NW SE NE 16	165 BOP + 33 BW	Shot 20 qts.
Rock Hill—Pence–Gericke 1	SE SW NE 16	15 BOP + 150 BW	—
Rock Hill—Pence–Gericke 2	NW SW NE 16	94 BOP	—
Rock Hill—Pence–Elbring 2	NW NW NE 16	124 BOP	—
Shell Oil—I. Elbring 1	SE NE NW 16	40 BOP	—
Rock Hill—Ed. Grimm 1	SE NE SE 17	D & A	—
Sohio Pet.—Keown 1	NW NE NE 17	103 BOP+3 BW	—

*Abbreviations:
- D & A—dry and abandoned
- IP —Initial production
- BOP —Barrels oil pumping
- BOF —Barrels oil flowing
- BOS —Barrels oil swabbing
- BW —Barrels water
- WO —Worked over
- OWWO—Old well worked over
- SWD —Salt water disposal

structure. Data from nearby wells indicate that the Ordovician system is represented by 175 feet of Maquoketa shale and limestone, 90 feet of Galena (Kimmswick) limestone, and about 475 feet of Plattin, Joachim, and Dutchtown limestones. The St. Peter sandstone lies just below the Dutchtown formation at a depth of nearly 3,000 feet.

STRUCTURE

In the upper part of the Silurian (fig. 4) and in the Devonian (fig. 5) and Lower Mississippian (fig. 6) strata, the structure at Marine is an elongate dome trending northeast-southwest, with its highest point near the northeast where there is nearly 100 feet of closure, and a lower slightly

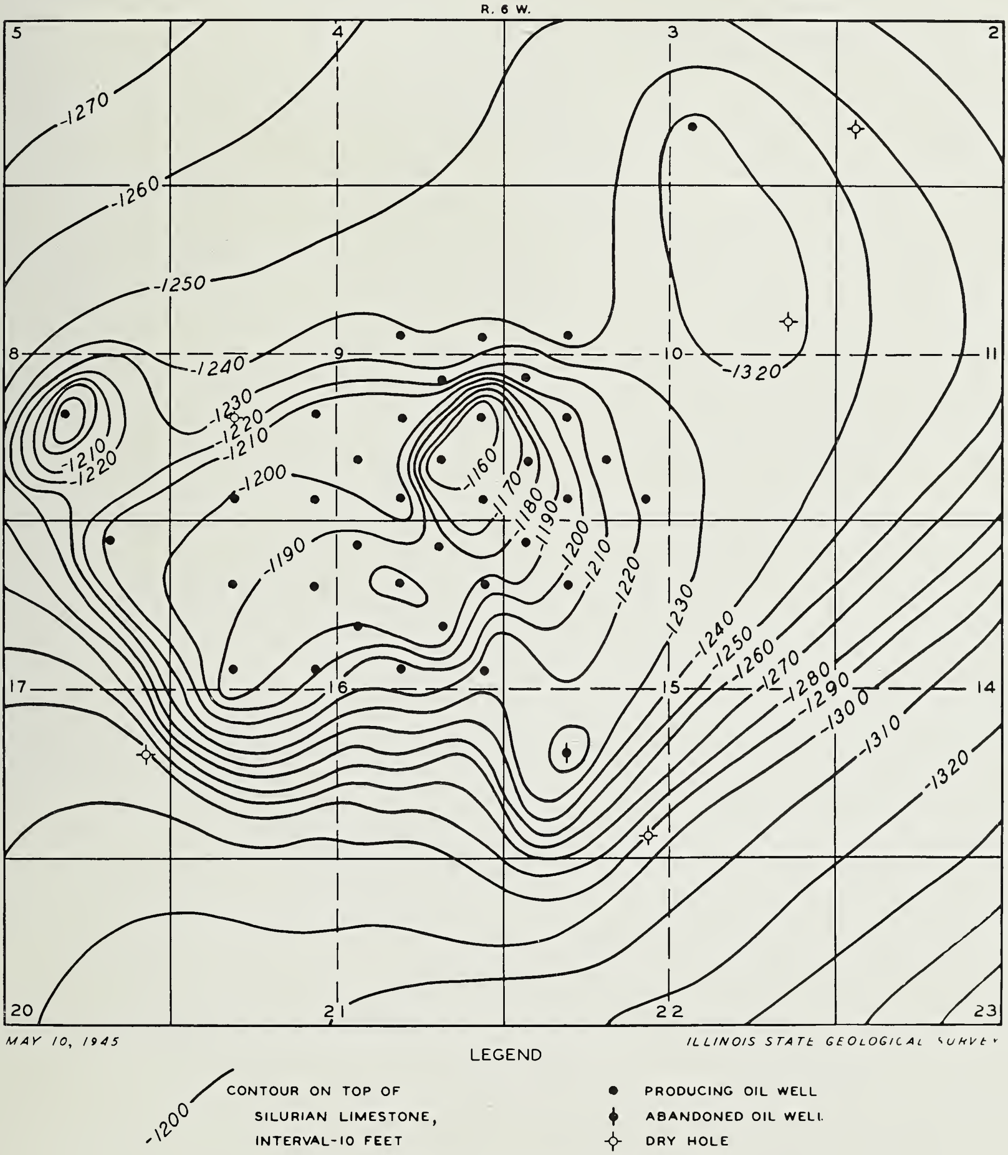


Fig. 4.—Silurian structure in the Marine pool.

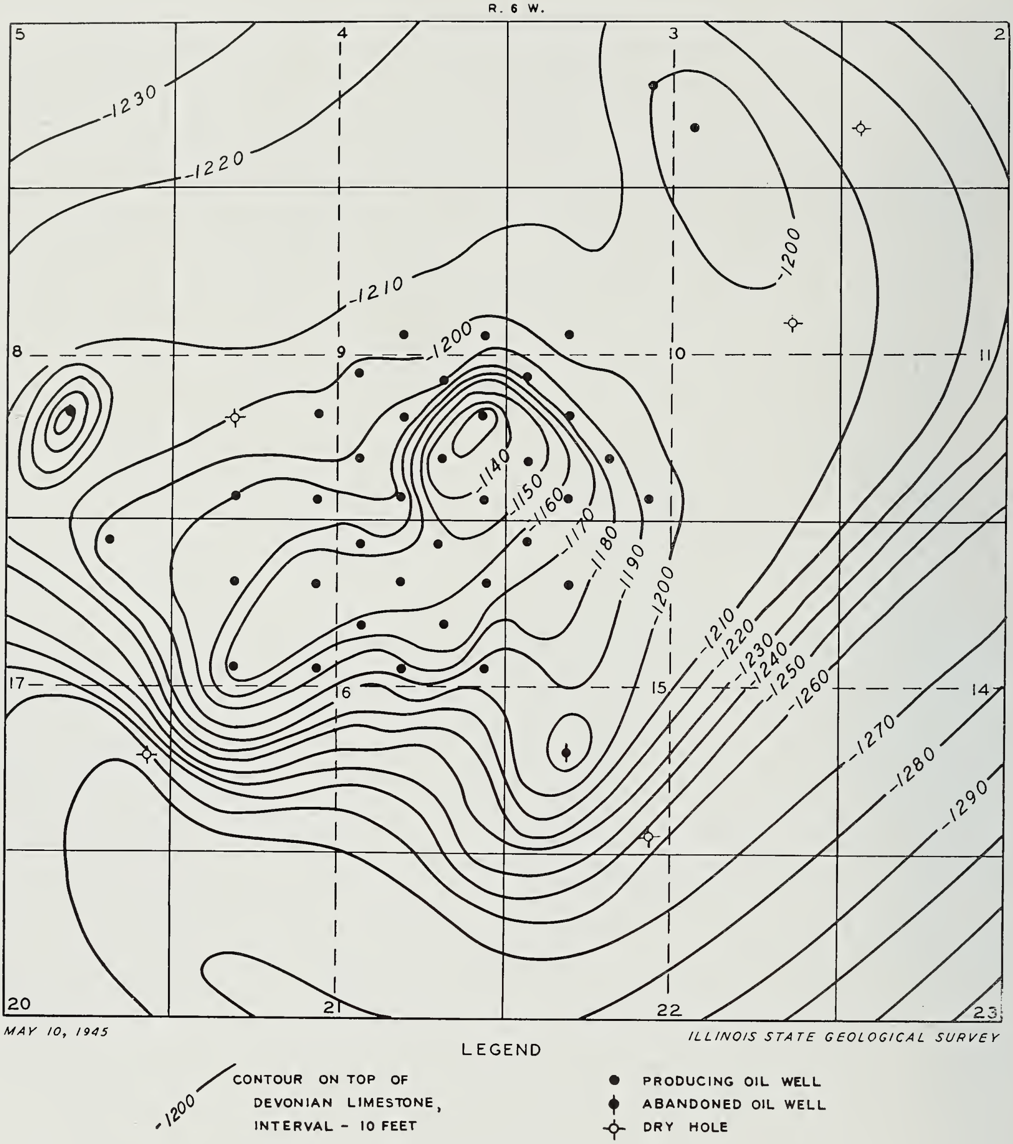


Fig. 5.—Devonian structure in the Marine pool.

larger area to the southwest where there is about 70 feet of closure. The Eason and Co.—Mayer No. 1 well, SE. ¼, NW. ¼, SW. ¼, sec. 15, is located high on structure, which is interpreted to indicate a southeastward extension of the structure (figs. 4, 5, 6, and 7), although it might possibly represent a separate structure of lesser magnitude. Other wells located structurally high in the immediate area are the Ginsberg-Brooks No. 1A in the SW. ¼, SE. ¼, NE. ¼, sec. 10, the Rockhill-Becker No. 1 in the NW. ¼, SW. ¼, SE. ¼, sec. 3, and the Obering-Bird No. 1 in the SE. ¼, NW. ¼, SE. ¼, sec. 8. These wells may indicate small subsidiary structures or a single more or less continuous flanking structure.

The structure on the top of the Ste. Genevieve limestone (fig. 7) reflects the structure of the underlying horizons but indicates

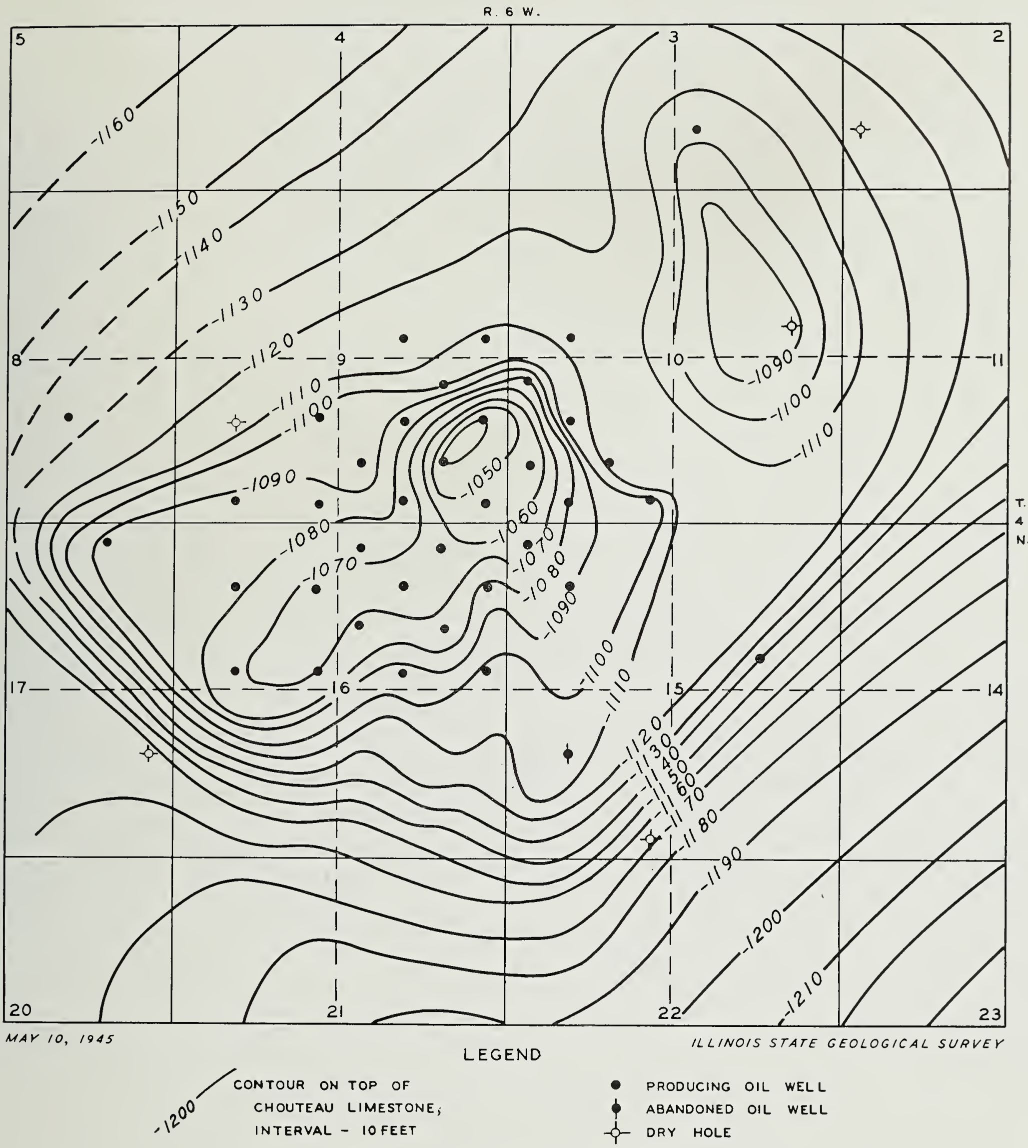


FIG. 6.—Chouteau structure in the Marine pool.

less deformation. The northeast-southwest trend is less pronounced than in the lower beds, and the amount of closure is somewhat less. Little information has been obtained on the relations of the Ste. Genevieve and Pennsylvanian structures. That which is available indicates a close conformity between the Ste. Genevieve and a thin limestone about 400 feet above it in the Pennsylvania strata.

The upper surface of the Chester series is irregular and reflects only to a limited extent the surface of the Ste. Genevieve limestone. The inequalities developed upon the Chester surface are in part compensated for by the deposition of a variable thickness of the lower Pennsylvanian sediments.

Only two wells in the immediate vicinity of the pool reach the Galena (Kimmswick) formation. These are the Eason and Co.

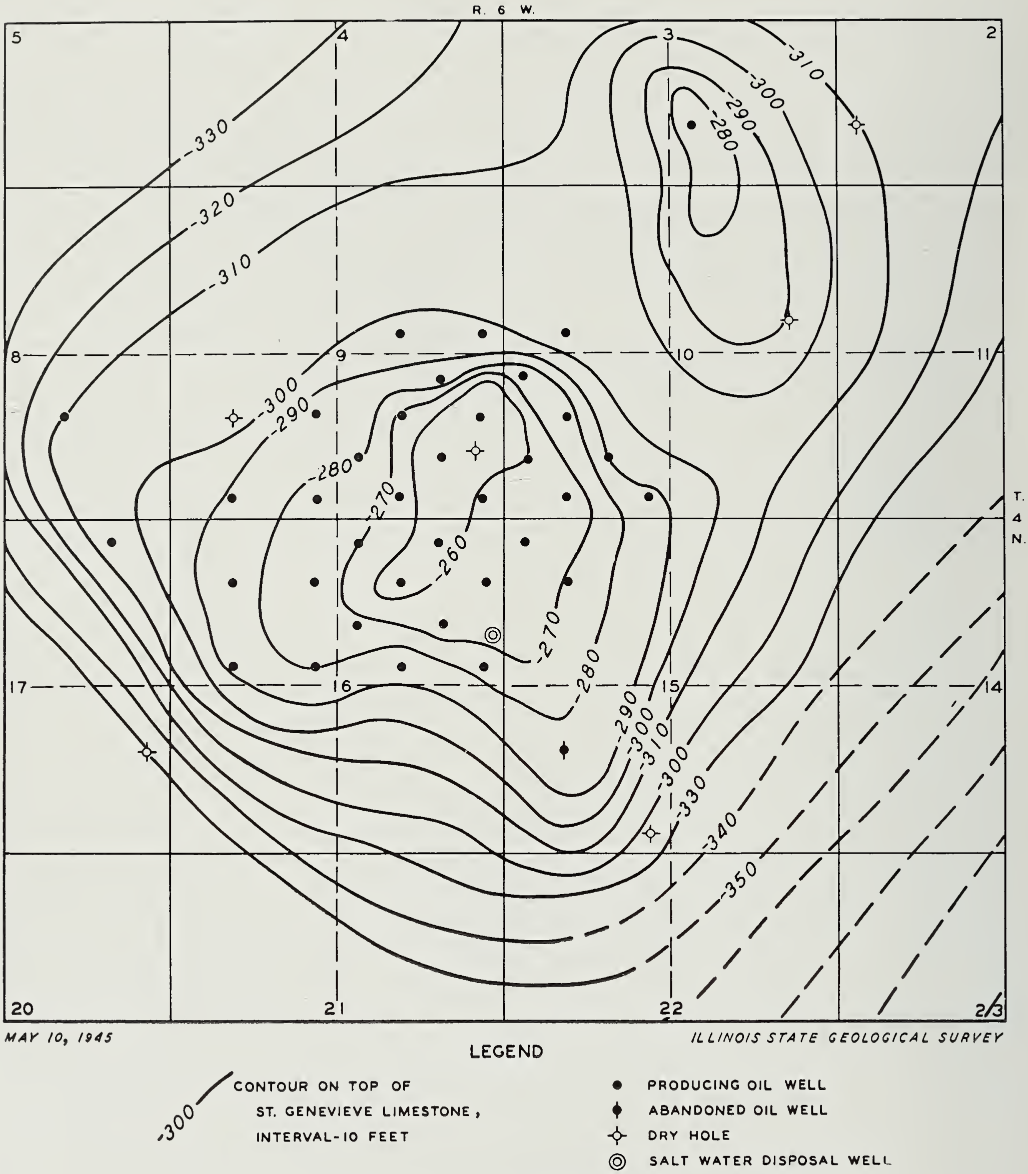


FIG. 7.—Ste. Genevieve structure in the Marine pool.

—Mayer No. 1 well in the SE. $\frac{1}{4}$, NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, sec. 15 and the Ryan Oil Co.—Kesner No. 1 well in the NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, SW. $\frac{1}{4}$, sec. 2. The elevations of the Galena in these wells appear to be relatively consistent with the regional elevations and suggest the possibility that the structure in the Galena is considerably less than it is in the overlying beds.

DEVONIAN AND SILURIAN STRATIGRAPHY

The following discussion of stratigraphy is confined to the Devonian and Silurian deposits because they form the immediate capping rocks and main reservoir of the pool. Cores from five rotary wells and one cable-tool well form the main source of information for the following lithologic descriptions. Additional data were secured from core chips and shot fragments, and from rotary- and cable-tool cuttings. The six cores represent a continuous sequence from about two feet below the top of the Devonian to about 63 feet below the top of the Niagaran.

Devonian System

The Devonian deposits consist of three distinct units which, in descending order, include a zone of undifferentiated shaly siltstones and the Cedar Valley and Wapsipinicon limestones. The thickness of the Devonian deposits ranges from 25 to 35 feet.

undifferentiated devonian siltstones

The highest deposits referred to the Devonian include 7 to 10 feet of massive firm calcareous and argillaceous siltstones of which the upper 3 to 6 feet are grayish-brown and the lower 4 feet are dark brown in color.

The upper grayish-brown siltstones are usually argillaceous, glauconitic, and highly calcareous but with occasional thin dolomitic lenses. Incorporated within this unit are thin laminae and lenses of dark brown argillaceous siltstones that are similar in lithology to the underlying siltstones. Fish remains and phosphatic pellets have been found near the base of the upper grayish-brown siltstone.

The top of the grayish-brown siltstone is indicated in electric logs by a characteristically small but sharp increase in impedance. A narrow zone in which semi-consolidated grayish-brown siltstones appear to have been incorporated in a matrix of dark brown siltstone marks the contact with the underlying beds and seems to represent a rapid intraformational facies change.

The lower dark brown siltstones are more argillaceous, less calcareous, and more highly pyritic than the upper but contain some lenses and laminae of grayish-brown siltstone and characteristically contain sand in the lower portions. The sand appears in thin lenses of grayish-brown siltstone or occasionally scattered through the dark brown siltstone but becomes more abundant with depth. Sometimes it is concentrated in silty, calcareous slightly glauconitic lenses which are inclined and suggest cross lamination. The individual sand grains are medium to coarse, frosted, and well rounded. Chert is also occasionally present near the base and is gray or brownish-gray in color and is slightly calcareous, argillaceous, glauconitic, and pyritic. The chert may be a silicified organic sand which in places is predominantly made up of sponge spicules and subordinately of ostracods, tentaculites, and echinoderm fragments. The individual fragments are medium to coarse in size and are uniformly sorted. Scattered pebbles of chert occur above the main zone of development. Small aggregates of sphalerite and galena are locally present.

Data on the contact relations with the overlying Upper Devonian - Kinderhook shale are lacking. The lower beds of the overlying shale are lithologically similar to the undifferentiated Devonian siltstones but are less calcareous and contain lenses of fine sand. The *Sporangites** in the Upper Devonian-Kinderhook beds are noticeably larger and more abundant than those in the Devonian siltstones.

The contact with the underlying Cedar Valley limestone is represented in the core of the Ohio Oil Co.—Grotefendt, I. C. R. R. Community No. 1 well in the SE. $\frac{1}{4}$, SW. $\frac{1}{4}$, NE. $\frac{1}{4}$, sec. 9. The contact is sharp and irregular. The basal four inches of the undifferentiated Devonian siltstone is very calcareous and sandy and contains scattered crinoid columnals as well as fragments of the underlying Cedar Valley limestone.

***Sporangites* is now considered a *nomen ambiguum*, and *Tasmanites* is proposed to replace *Sporangites*. Schopf, Wilson and Bentall, Illinois Geol. Survey Rept. Inv. 91, 1944.*

A small variety of *Sporangites* occurs commonly in these siltstones. Megascopic fossils are confined to two species of brachiopods, one of which is referable to *Lingula*. Individuals of both species are fairly abundant. Ostracods from the basal chert suggest a post-Cedar Valley pre-Cerro Gordo age.[1]

CEDAR VALLEY FORMATION

The Cedar Valley formation in the Marine pool area includes 3 to 10 feet of sandy argillaceous limestone beds which are interlaminated with sandy shales. Depending upon the proportion of sand and shale and upon the degree of segregation of the limestone and shale fractions, the formation is either a more or less continuous sequence of slightly argillaceous limestones with occasional discontinuous shale partings or a thin-bedded to thinly laminated series of limestone beds with interbedded sandy shales.

The limestone is gray, white, brown, or buff, sometimes with dark gray or buff mottling, and represents coarse, occasionally medium to fine-grained coquinas or "semi-coquinas" of skeletal debris. The organic constituents consist predominantly of dissociated crinoid columnals and to a lesser extent of fragmentary corals, brachiopods, and bryozoa. Secondary replacement by silica, glauconite, and pyrite is common. However, replacement by glauconite and silica is seldom complete. Large scale replacement by silica is rare and confined to aggregates which are free of argillaceous impurities. Selective pyritization of bryozoan fragments is apparent.

The interstitial spaces of the coquina may contain sand, gray or brown clay, silt, glauconite, pyrite, or secondary calcite in any proportion or combination. The sand is commonly medium to coarse, rarely fine-grained, and is well rounded and frosted. The pyrite is usually finely disseminated and is found in the shaley portions. A small variety of *Sporangites* occurs in the argillaceous and silty portions and is similar to that in the overlying undifferentiated siltstones.

The shale laminae within the limestone are gray to black, rarely light brown, and are locally glauconitic, pyritic, or sandy. Their composition is similar to that of the argillaceous portions of the coquina matrix. Because the sand content is variable the laminae may actually range in lithology from a shale to an argillaceous sandstone.

Conglomeratic zones occur locally at the top and bottom of the formation. The pebbles in the conglomeratic phase near the top consist of chert and medium to dark gray finely crystalline limestone, both of which are foreign to the Cedar Valley limestone in this area. The pebbles in the basal beds were derived from the underlying Wapsipinicon, and light to dark gray chert pebbles and abraded corals and bryozoa are present. The limestone matrix is free from shale, contains less silt and more sand than the rest of the formation. Very thin lenses of silty sand are commonly associated with the conglomeratic zone. Ill-defined patches of dark brown pyritic siltstone containing abundant small *Sporangites* are present and may represent pebbles which were only semi-consolidated at the time of their incorporation into the sediment.

The irregular contact with the overlying beds has been described. A sharp lithologic break marks the contact of the Cedar Valley and underlying Wapsipinicon limestone. From the evidence presented below in connection with the development of joints and fissures it appears probable that the Cedar Valley limestone rests unconformably upon the Wapsipinicon formation.

Correlation of these beds is based upon lithologic similarity and continuity with beds of Cedar Valley age in western Illinois.

WAPSIPINICON FORMATION

The Wapsipinicon is represented by 11 to 15 feet of limestones and occasionally dolomites.

The limestones are dense and lithographic to finely, rarely medium, crystalline, and are brown or buff, occasionally

[1] C. L. Cooper, personal communication.

dark gray in color. Isolated medium to coarse sand grains which are well rounded and frosted occur throughout the limestone. Toward the bottom of the formation the sand content increases slightly and the limestone becomes more silty. Chert, which occurs at random throughout the formation, is usually limited but may make up as much as 60 percent of the rock. In color it ranges from brown to gray or black. Discontinuous fractures of microscopic size are common in the limestone. The fractures and minute vugs and fossil cavities are often lined or filled with secondary calcite and sometimes with glauconite or chalcedony. Minute glauconite spots and dendrites of manganese oxide occur rarely in the top of the formation. Fossils are occasionally silicified. Stylolites are locally developed.

The dolomites are buff to brown in color and finely to medium crystalline. Fossil casts and molds are characteristic. Some of the fossil cavities are filled with secondary calcite. Sand grains similar to those in the limestones are locally present. Patches of dolomite within the limestone are common, particularly along the margins of fissures and joints which have been enlarged by solution.

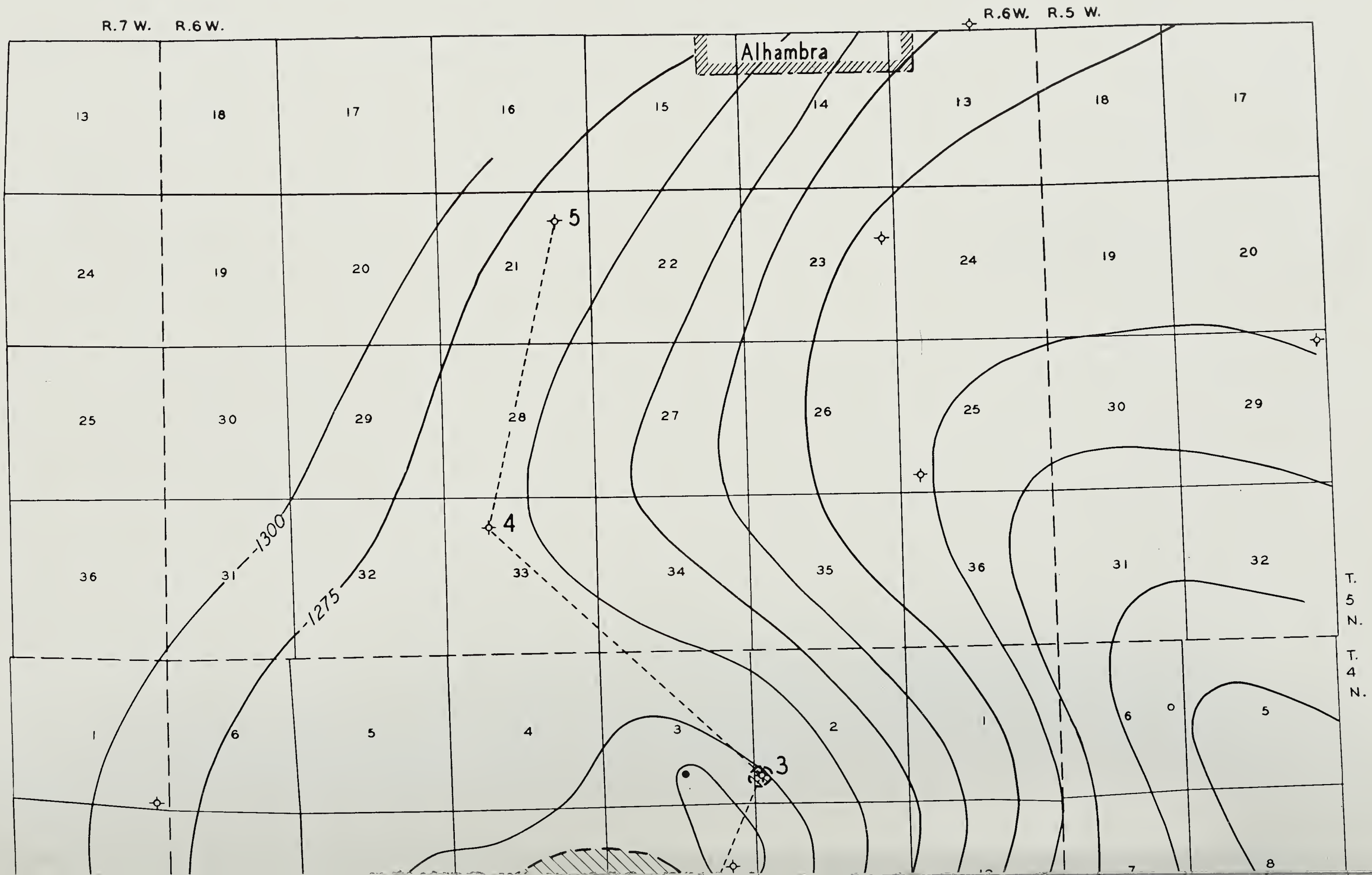
A very sandy conglomeratic phase about seven feet below the top of the Wapsipinicon is represented in the core of the Shell Oil Co.—Elbring No. 1 well (sec. 16, T. 4 N., R. 6 W.). The rock is a sandy dolomitic limestone which is dark brown with light brown mottled areas, dense to finely sucrose, and is penetrated by trail-like oval shaped worm tubes. Sand is unevenly distributed through the limestone matrix but less concentrated than in the tube fillings. Commonly the light brown areas contain more sand than does the darker brown dolomitic limestone. Unsorted well rounded pebbles of dark gray chert and of buff and light brown finely crystalline limestone with a few scattered sand grains are common. The material in the worm tubes consists of about 60 percent sand grains in a matrix of white to buff finely crystalline sucrose limestone which is occasionally glauconitic. The sand is similar to that in the rest of the zone and ranges from rounded to rarely subangular in shape and is fine to coarse, frosted and unsorted. The entire conglomeratic zone in the Shell-Elbring well is $2\frac{1}{2}$ feet thick.

These beds are assigned to the Wapsipinicon formation on the basis of lithologic similarity and subsurface continuity with similar beds in western Illinois.

Information on the contact relations of the Devonian and Silurian deposits is limited to cores from three wells. That from the Sohio—Imbs No. 1, NW. $\frac{1}{4}$, NE. $\frac{1}{4}$, SE. $\frac{1}{4}$, sec. 7, shows the contact of the Wapsipinicon and the interreef facies of the Silurian. The surface of the contact is very irregular and has been enlarged by solution accompanied by sand and clay infiltration (fig. 8a). The basal 12 inches above the contact plane appears to be gradational in lithology. Lenses in the basal few inches suggest incorporation of Niagaran material in the basal beds of the Wapsipinicon. The core of the Sohio—Imbs No. 2 (SE. $\frac{1}{4}$, SE. $\frac{1}{4}$, SE. $\frac{1}{4}$, sec. 1, T. 4 N., R. 7 W.) does not show the actual contact, but the basal Wapsipinicon deposits are again more or less transitional with the Niagaran. The cable-tool core of the Shell—Elbring No. 1 (SE. $\frac{1}{4}$, NE. $\frac{1}{4}$, NW. $\frac{1}{4}$, sec. 16) does not show the actual plane of contact but there is an abrupt change from the typical Wapsipinicon lithology to that of the underlying detrital reef sand.

FISSURE SYSTEM

The rocks of the Wapsipinicon formation and of the upper parts of the Niagaran series contain many fissures (fig. 8a). This is known from recovery of a number of filled crevices in cores, as well as recovery of sand and green shale in most well cuttings from the Niagaran and Wapsipinicon formations. The fissure system is most strongly developed in the Wapsipinicon and in the upper beds of the Silurian pink detrital limestone and is less pronounced at greater depths. The interreef beds of the Niagaran show few fissures, and those which are present are confined to the uppermost few feet.



R.7 W.
R.6 W.
R.6W.
R.5 W.
Alhambra
T. 5 N.
T. 4 N.
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-1275
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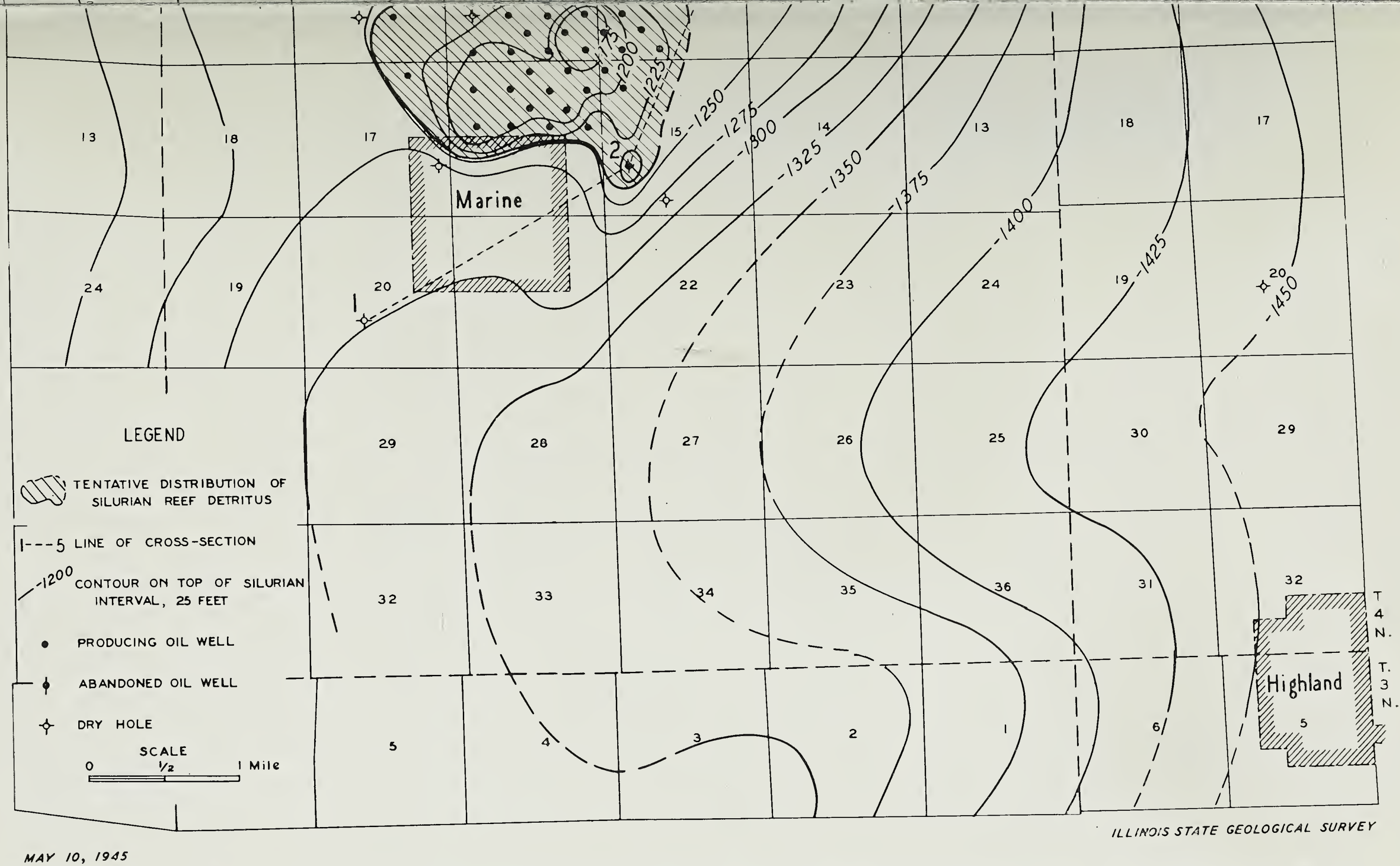

FIG. 12. Map showing regional structure of the top of the Silurian and present known distribution of the upper Silurian reef detritus. (See fig. 11.)

The intricate system of fissures interconnects with bedding planes and occasionally with joints, stylolites, and worm-borings. The fissures are commonly irregularly enlarged by solution and may attain a width of two inches. The walls are smooth or may be sculptured in such a way as to indicate solution accompanied by movement. The main fissures and solution-enlarged bedding planes are always tightly filled with clay or sand and commonly by both. A direct relationship appears to exist between the width of the fissure and the proportionate filling of sand. The widest fissures are as a rule filled with tightly packed calcareous sand. Fragments of wall rock with solution resorbed margins occur commonlly within the sand matrix and are occasionally arranged in discontinuous bands. What little clay occurs in the large fissures is concentrated along the wall and around the fragments of wall rock. With decrease in width, the fill of the main fissures consists primarily of clay and to a lesser extent of sand which is scattered at random through it. Secondary calcite is sometimes present along the fissure walls and is most prominent in the zone of deepest penetration. In the reef dolomite, clay fillings are still common but sand is rare. Smaller fissures commonly branch off the main ones and penetrate the wall to a variable depth. In the pink detrital limestone they interconnect with the pores of the interstitial matrix and with the vugs. The fill of these secondary fissures is similar to that of the main fissures but clay is quantitatively dominant.

In physical character the sand in the fissures is coarse to fine and occasionally grades to silt. It is well rounded, frosted, and only occasionallly sorted. The clay is light to dark green, less commonly gray, and rarely white. Finely disseminated pyrite occurs adjacent to the wall rock and as megascopic crystals in the clay and occasionally in the sand. Marcasite and siderite is also of rare occurrence in the sand.

Since the fissures do not extend into the Cedar Valley formation it is assumed that the fissure system was developed in post-Wapsipinicon pre-Cedar Valley time. Surface connection for the fissures appears to have been necessary to account for the sand and clay fill. The absence of clay in the Wapsipinicon formation and in the Niagaran reef rocks indicates that derivation was not from these sediments. In addition, the Wapsipinicon does not appear to be sufficiently sandy to provide the amount of sand present in the fissures. The source of clay and sand is at present unknown. It is interesting to note however that the Hoing sand at Colmar-Plymouth oil field, and the shale of the Independence formation of Iowa were laid down in the same interval between Cedar Valley and Wapsipinicon time and may have some mutual relation.

Silurian System

The Silurian rocks, in contrast to the meager development of the Devonian deposits, are represented in thicknesses which range from 430 to 570 feet. The post-Bainbridge Niagaran[2] rocks display considerable variations in thickness and lithology. Two well developed facies realms are present, one of which coincides with the area of reef development, and the other with the normal or interreef area. The electric log characteristics of these two realms are depicted in figure 9. Below these two facies, the Bainbridge, Sexton Creek, and Edgewood formations extend through both areas, and, except for differences in thickness, are presumably equally developed in both.

In the following treatment, the lithologies of the two facies realms of the post-Bainbridge Niagaran are dealt with separately. The uppermost 63 feet of the reef and the uppermost 20 feet of the normal or interreef facies are represented by cores. Description of the underlying Silurian deposits is based upon electric logs and sample studies.

[2] The term Bainbridge is here used to include only those dominantly red rocks and associated deposits at the base of the Niagaran although it seems probable that some of the lower strata of the reef and possibly of the normal or interreef strata may also be of Bainbridge age. The term Niagaran is similarly used to include all the Silurian above the Sexton Creek formation although it is possible that some of the higher beds referred to the Niagaran in this area may ultimately prove to be of younger Silurian age.

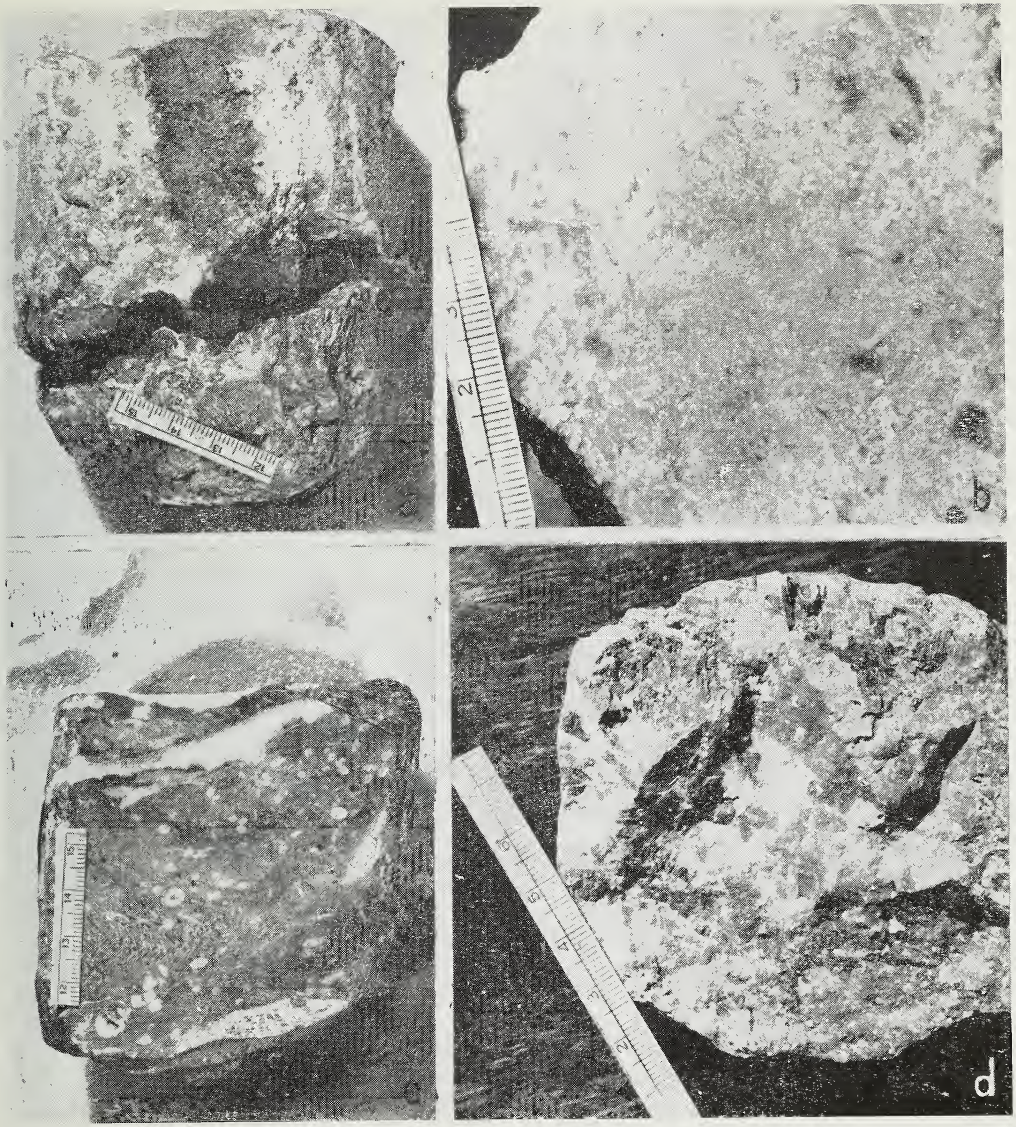

Fig. 8.—Lithologic character of Silurian reef deposits. Scales are in centimeters.

a. Clay-filled fissure in the reef core rock.
b. Reef-capping detrital limestone.
c. Inclined reef flank.
d. Typical reef core.

REEF AND ASSOCIATED DEPOSITS OF POST-BAINBRIDGE NIAGARAN AGE

Pink detrital limestone. — Throughout the pool area the highest Niagaran deposits consist of a variable thickness of coarse white, pink, or buff detrital limestone (fig. 8b). Near the base of the zone the rocks become slightly dolomitic and the color changes to various shades of gray. The buff, white, and gray limestone is characteristically mottled with pink.

The rock is made up of calcareous skeletal elements and fragments, mostly dissociated crinoid columnals and bryozoa, brachiopods, corals, stromatoporoids, and rarely gastropods, and calyx plates and brachial ossicles of crinoids, which are packed into a loose coquina and cemented with calcite.

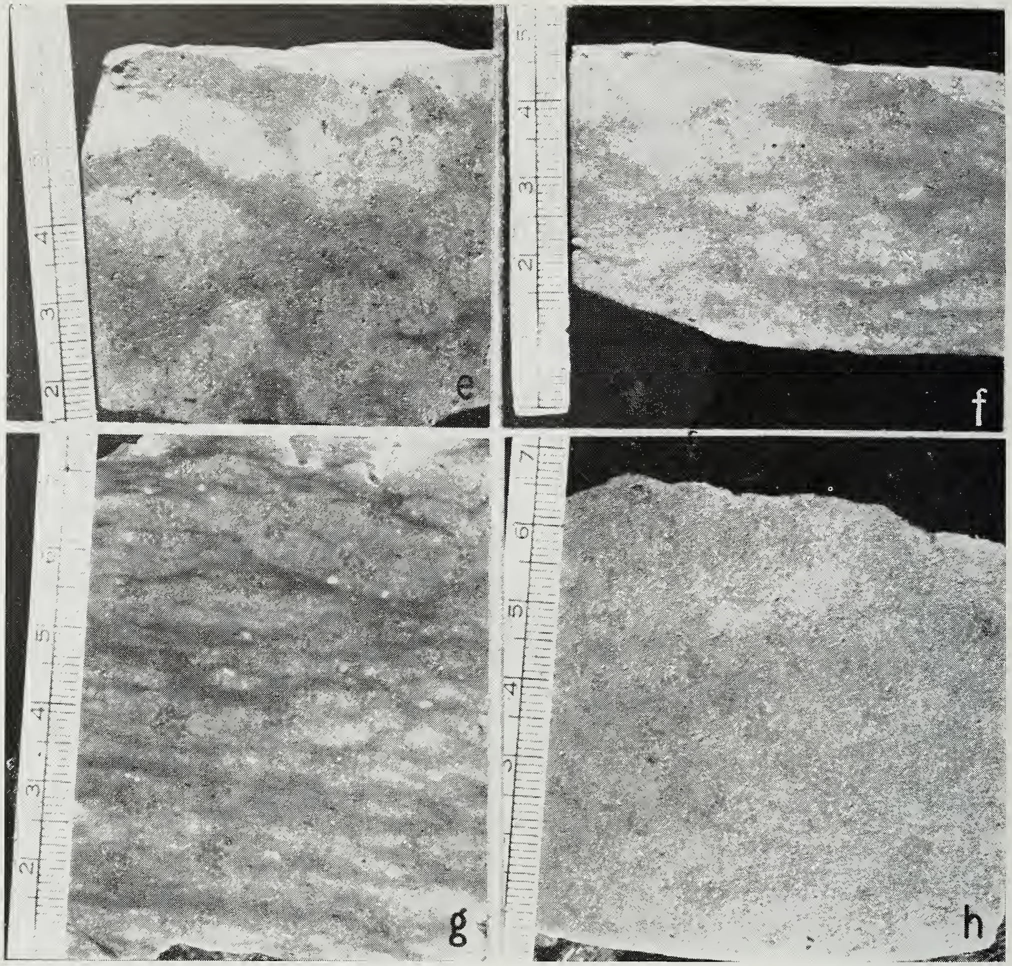

Fig. 8, e-h. Lithologic characters of Silurian interreef deposits. Scales are in centimeters.

Occasionally bryozoa and corals are the most common faunal elements. The size and ratio of the fossil constituents varies somewhat horizontally and vertically. The grain size of these strata made up dominantly of corals and bryozoa is generally larger than is that of the crinoid columnal coquinas. Large heavy shelled brachiopods, colonial corals, and stromatoporoids occur at random throughout the coquina.

The interstitial spaces of the crinoidal limestone are largely filled with secondary calcite and less commonly with light green clay. These limestones made up of the larger bryozoan and coral fragments sometimes contain small fragments of other forms in the interstitial spaces. Vugs of irregular size and shape occur throughout the rock. These are commonly located within brachiopods, in the interskeletal spaces of the stromatoporoids and corals, along discontinuous fissures, and in the interstitial spaces of the coquina. Many of the vugs are more or less filled with secondary calcite. Stylolites and stylolite seams are common, and bedding planes are frequently interlocked in styolite fashion, suggesting solution along those surfaces.

Bedding appears to be massive but where bedding planes are present in cores they are more or less horizontal in the upper part of the section and inclined in the lower. Dips

range from 10 to 20 degrees but occasionally up to 45 degrees where they have been altered by solution.

Toward the base of the pink detrital limestone the strata grade into and interfinger with the underlying reef dolomite and dolomitic limestone. The colors of the rocks are darker in this zone, and poorly defined areas of medium to fine-grained darker slightly dolomitic limestone are present. In these patches, partial recrystallization and dolomitization has altered the rock so that the individual constituents of the coquina are less distinct.

Inasmuch as only two wells in the pool area extend through the detrital limestone, reliable figures on thickness are not available. The two wells which penetrate the unit show thicknesses of 6 and 22 feet, while another well penetrated 39 feet of the limestone without going completely through it. Because there is apparent gradation with the underlying beds, it is possible that these figures simply reflect depth to the zone of recrystallization and dolomitization.

Reef Core and reef flank beds.—(figs. 8c and d). The following description of the Niagaran beds which underly the detrital limestone of the pool area is based upon 40 feet of core and 372 feet of rotary samples from the Eason—Mayer No. 1 well (SE. $\frac{1}{4}$, NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, sec. 15). The core consists of dolomite, dolomitic limestone, and some pure detrital limestone. The rocks appear to be massively bedded but occasionally show bedding planes that are inclined with dips ranging from 20 to 45 degrees, usually less than 30 degrees. The bedding planes are occasionally grooved and striated parallel to the plane of dip and suggest stylolitic interlocking. A film of green to gray clay and a thin zone of secondary calcite sometimes occurs along the bedding plane contacts. Normal stylolites are also present and are capped by a thin film of green clay.

Dolomites and dolomitic limestone form most of the core. Clastic limestones are relatively rare and are developed most commonly in the upper portion of the core where they are interbedded with dolomitic limestone. Small dolomitized areas are present in practically all the limestone. It appears likely that poor recovery in the lower part of the core was associated with the occurrence of pure vesicular dolomite. The color of the dolomitic rocks is dominantly gray, the darker shades being associated with the purer dolomites. Mottled zones reflect random areas of dolomitization.

The limestones are light gray, white, or buff and are rarely mottled with pink. They are medium to coarsely crystalline and resemble in composition the uppermost pink detrital limestone. One flat buff pyritic chert nodule represents the only occurrence of chert found in the core. Localized brecciation is suggested by the occurrence of angular areas of light gray fine-grained dolomite within the limestone. The large fossils consist of solitary corals, bryozoa, crinoids, and brachiopods.

The dolomitic limestone varies from dense to vesicular, from medium to fine-grained or sucrose, and may enclose coarsely crystalline beds. Fossils in the more dolomitic portions are represented only by casts and molds. The large fossils include representatives of the same groups which occur in the limestone.

The dolomites are dense to finely sucrose and vesicular. Discontinuous intersecting fissures occasionally produce a brecciated appearance. Random distribution of fossils of various sizes is common. The orientation of the fossils is variable, and angles up to 80 degrees with horizontal were noted. The percentage of recognizable fossils is smaller than in the limestone and dolomitic limestones. The average size of the organisms also appears to be larger than those in the other two lithologies. The fossil casts sometimes show resorbtion and irregular enlargement. Deposition of secondary calcite in the casts and molds and in the fissures, vugs, and pore spaces ranges from a thin film to complete filling. In contrast, secondary calcite in the limestones is largely confined to fossil cavities and interstitial spaces of the coquina.

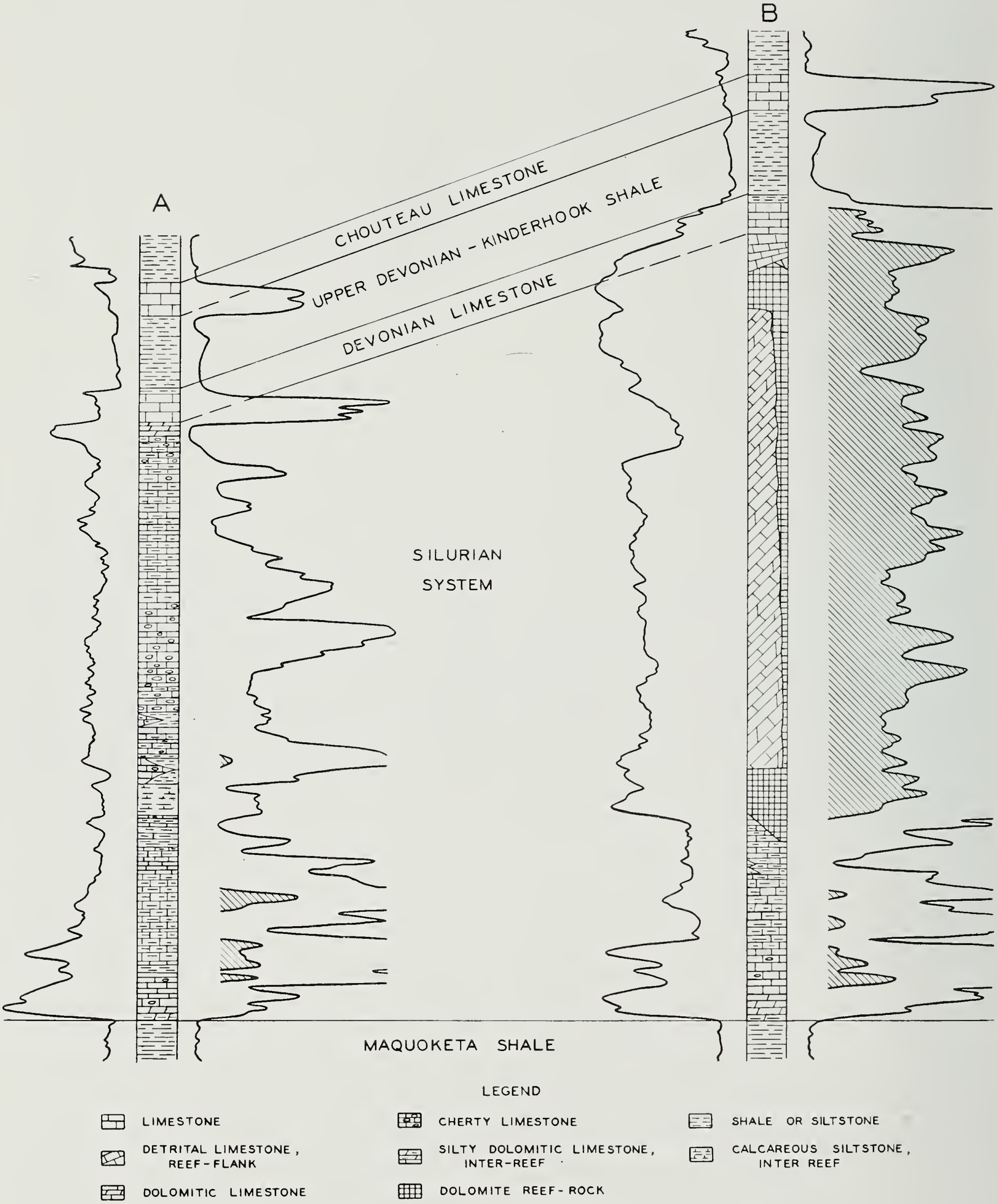

Fig. 9. Characteristic electric logs of Niagaran interreef (A) and reef (B) deposits.

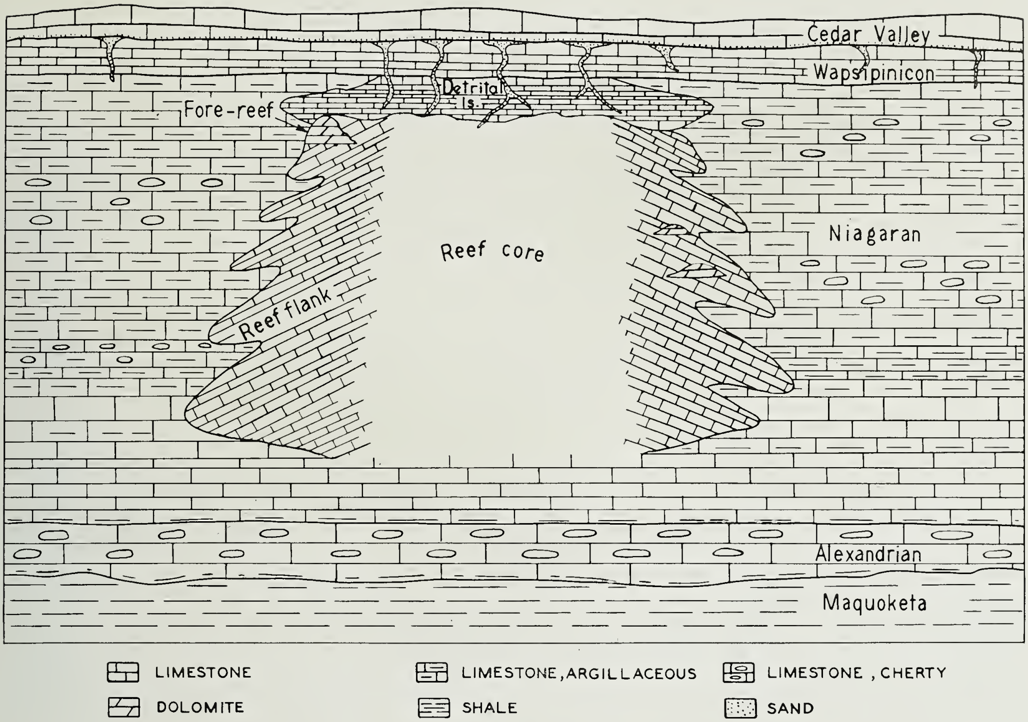

FIG. 10. Diagrammatic cross-section of Marine reef.

Rocks similar to those described above extend downward for an additional 372 feet below the base of the core. Pure dolomites are less commonly represented and are concentrated in narrow zones with the greatest development near the base where there is a dolomite zone 35 feet thick. Pure limestones and to a lesser extent dolomitic limestones form the bulk of the sequence. A recurrence of the pink mottled coarsely crystalline limestone is present 90 feet below the top of the Niagaran.

Below the zone of reef development there is a 10-foot zone of transition into the underlying red facies of the Bainbridge. This zone consists at the top of greenish to brownish-gray and gray dolomitic fine-grained argillaceous and silty limestones. Downward the dolomite content is reduced and the silt and carbonate fractions are more sharply segregated. White partly pinkish mottled crinoidal limestone and greenish-gray calcareous siltstone with scattered crinoid columnals suggest the underlying Bainbridge.

The fossil assemblages of the reef facies, including both the reef and reef flanks, comprise stromatoporoids, colonial corals of the genera *Favosites* and *Halysites, Pycnostylus guelphensis,* and a number of unidentified large solitary corals. Among the extremely abundant crinoidal remains, all of which are dissociated, the genera *Crotalocrinites* and *Gissocrinus* alone have been recognized. Heavy shelled pentameroid brachiopods, bryozoa, gastropods, and pelecypod fragments are present.

INTERREEF AND ASSOCIATED DEPOSITS OF POST-BAINBRIDGE NIAGARAN AGE

The deposits of the normal or interreef realm are variable in their lithologic composition. The diagrammatic cross-section (fig. 10) which represents an interpretation of available well records expresses the variable lithologic character of these depos-

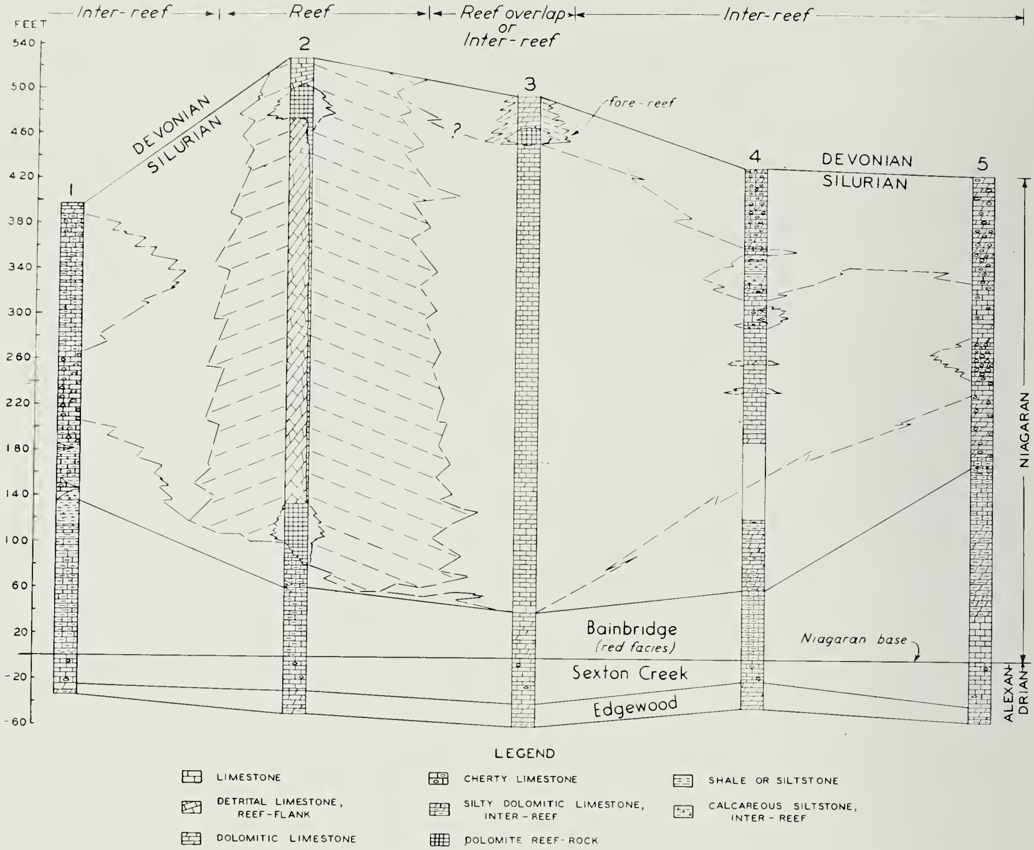

Fig. 11. Cross-section showing Silurian reef and interreef facies relationships. (See fig. 12.)

its. Recurrence, interfingering, and gradation of the several lithologies reflect rapid lateral and vertical change in facies (figs. 8e, f, g, and h and 11). The main constituents of the Niagaran interreef beds above the Bainbridge are limestones, dolomites, and calcareous siltstones. In color the beds are usually gray, green or white, although occasionally they are brown. Clay and silt are almost invariably present in the carbonate rocks to a greater or lesser extent.

The limestones are white, buff, gray or greenish-gray in color, finely to coarsely crystalline, and may be silty, argillaceous, and cherty. The coarse inclusions in the limestone include aggregates of skeletal elements, mostly crinoid columnals and less commonly bryozoan and coral remains. The fossil density commonly approaches but rarely attains that of a coquina. The organic remains are small and suggest derivation from fragile skeletal elements. Clay occurs in finely disseminated form or is concentrated in thin beds of shale. Where it is disseminated the clay content is commonly indicated by a greenish color. Finely disseminated pyrite is present in the argillaceous zones. Numerous bryozoan remains characterize the shaly portions of the limestone. Chert is white and bluish-gray and commonly encloses dissociated spicules of siliceous sponges. Complete sponges are present but rare.

The dolomites are usually porous, white, buff, and light gray and are finely crystalline. They are usually silty and may be cherty and argillaceous. The silt, chert, and argillaceous constituents are similar to

those in the limestone. Diagenetic removal of the carbonates of the original fossil skeletons is demonstrated by the presence of casts and molds. The same phenomenon is also noticeable in the very silty limestones. Replacement by secondary calcite and less commonly by silica is of frequent occurrence. The interstitial pore spaces and scattered small vugs are either lined or filled with secondary calcite.

The siltstones are dark brown and brownish-gray in color, pyritic, and commonly highly calcareous. They grade into and apparently are interlaminated with very silty light brown to brownish-gray limestones. Minute chitinous fossil fragments are present in the siltstones.

The lithologic types usually grade into one another, and sharp contacts are rare. Clay is concentrated in lenses, in nodules of argillaceous limestone, or in partings between limestone beds. In some cases the distribution of the clay suggests that the rock represents an intraformational conglomerate.

The thickness of the Niagaran deposits in the interreef areas is 395 feet in the Bayer—Grimm No. 1 well (SE. $\frac{1}{4}$, NE. $\frac{1}{4}$, SW. $\frac{1}{4}$, sec. 20). Thicknesses of 425 feet are reached two to three miles north of the pool area and are interpreted in terms of regional thickening. In the Ryan—Kisner No. 1 well (NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, SW. $\frac{1}{4}$, sec. 2) which is intermediate with respect to both reef and interreef areas, the Niagaran deposits are 502 feet thick.

The fossil remains of the normal or interreef facies comprise, in order of decreasing abundance, crinoidal remains, isolated spicules and rarely complete skeletons of tetractinellid sponges (Astylospongidae), fragile solitary and less commonly heliolitid corals, and bryozoa.

INTERFINGERING OF REEF AND NORMAL FACIES

Although most of the wells and cores studied conform to the general patterns stated above for reef and interreef lithologies, there are several instances in which there are mixtures of reef and interreef lithologies within a given well (fig. 11).

Thus in the marginal Eason—Mayer No. 1 well (SE. $\frac{1}{4}$, NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, sec. 15), the beds which immediately overly the abnormally thin Bainbridge sediments consist of a fine silty argillaceous dolomitic limestone which is typical of the interreef or normal sediments in the upper part of the Silurian.

In the Obering—Bird No. 1 well (SE. $\frac{1}{4}$, NW. $\frac{1}{4}$, SE. $\frac{1}{4}$, sec. 8), the pink detrital limestone (which normally directly overlies the reef rock) is underlain by a very finely crystalline gray dolomite of the interreef type.

The entire post-Bainbridge Silurian sequence in the Ryan Oil Co.—Kisner No. 1 well (NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, SW. $\frac{1}{4}$, sec. 2), is poorly understood. The highest deposits consist of white, medium to fine dolomites which are mottled with pink and red. The larger part of the Niagaran section between the upper pink detrital limestone and the Bainbridge below consists of white, medium to fine, crystalline limestone with a few lenses of dolomite and occasional shale partings. Inspection of the electric log indicates that the strata present are directly continuous laterally with normal interreef deposits, but differ from them by being characterized by a very considerably higher impedence.

AGE OF UPPERMOST DEPOSITS

A systematic study of the fossils in these deposits has not been undertaken. The few forms listed below were secured from limestone beds immediately below the pink detrital limestone in the core of the Eason—Mayer No. 1 well. The coral was identified by Dr. R. S. Bassler of the National Museum, Washington, D. C.

Crotalocrinites sp.
Gissocrinus sp.
Pycnostylus guelphensis

The generic identification of *Crotalocrinites* is based upon a characteristic portion of the root. In the Niagaran deposits of northeastern Illinois this form ranges from the upper beds of the Waukesha into

beds of Guelph age.[3] In northwestern Illinois it occurs in beds of Port Byron age. The genus *Gissocrinus* until recently has been thought to be restricted to the Laurel, Louisville, and Brownsport beds of southern Indiana, Kentucky, and Tennessee. Its presence in beds of Waukesha to Guelph age in northeastern Illinois and in the Liston Creek formation of northern Indiana has been demonstrated.[4] The specimen of *Gissocrinus* is closely related to *Gissocrinus quadratus* Springer. *Pycnostylus guelphensis* is confined to the youngest Niagaran deposits of Guelph age of northern and eastern North America. This faunal evidence, although meager, suggests a Guelph age for the uppermost reef rocks in the Marine area. It is hoped that a detailed study of the numerous forms yet unidentified in deposits of both reef and interreef facies will establish a firmer correlation.

INTERPRETATION OF THE POST-BAINBRIDGE NIAGARAN FACIES

An analysis of the data presented above furnishes certain criteria which lead to the following interpretation of the characters and relationships of the reef and normal or interreef facies. Contrasting features of the two facies are expressed by differences in lithology, thickness, bedding characteristics and fossils.

Lithology.—The lithologies of the pool area, above the Bainbridge, can be readily distinguished from those of the surrounding area by the absence of silt, clay, and chert. Pure limestones and dolomites form the characteristic lithologies of these pool deposits. Coarsely crystalline limestone in which the individual coquina constituents are also relatively coarse are prominent within the pool area.

Thickness.—In the area under discussion, the Niagaran deposits display a regional thickening of approximately ten feet per mile toward the southeast. Locally however the two facies complexes differ in thickness by as much as 130 feet. The increase in thickness is confined to the pool area whereas those of the surrounding area are more or less consistent with the regional trend.

Bedding.—A striking attribute of the deposits in the pool area is the presence of beds with dips ranging from 10 to 45 degrees.

Fossils.—The fossils in the pool facies are characterized by large size, and robust to heavy skeletal development. In contrast, the fossils of the surrounding facies complex are uniformly fragile and predominantly smaller.

The pool area forms an insular occurrence in the surrounding facies complex (fig. 12) which possesses features diagnostic of deposition in a still-water environment. The sediments represent a combination of chemically precipitated carbonates, fine-grained clastics, and skeletal aggregates of autochthonous organisms. The chert represents localized concentrations of silica which may have been in part derived from the siliceous skeletal elements of autochthonous sponge colonies. The size and fragile character of the fossil constituents in general, and the relative abundance of tetractinellid sponge fragments in certain beds in particular, corroborate deposition under still-water conditions.[5]

In contrast, the facies complex above the Bainbridge in the pool area reflects an areally restricted occurrence of rough-water environment. The large mound-like form and its variously inclined beds are characteristic features of reef structures. Thus it is recognized that the pool lithologies represent an isolated reef in the surrounding normal or interreef facies. The reef lithologies are entirely made up of the remains of the reef population in the form of actual skeletal elements and water-abraded and selected derivatives. The physical aspect and composition of the fossil assemblages are in agreement with those from other Niagaran reefs. The fauna of the detrital fans of the inclined reef flank include abundant stubby and semiglobular colonies of

[3] Lowenstam, H. A., Biostratigraphy studies of the Niagaran interreef deposits of northeastern Illinois; State Museum Sci. Papers No. 3, in press.

[4] Idem.

[5] Idem.

Favosites, heavy shelled pentameroid brachiopods, large fragmentary colonies of *Halysites,* and remains of large robust crinoids. It is noteworthy that representatives of the genus *Crotalocrinites* in the Niagaran deposits of northeastern Illinois are confined to the reefs. In contrast, the previously known representatives of *Gissocrinus* were interreef dwellers. The occurrence of *Gissocrinus* in the reef flank beds at Marine is similar to its occurrence in the contemporaneous reef at Thornton in northeastern Illinois in which *Gissocrinus,* together with other faunal elements of the interreef realm, encroaches on sheltered parts of the reef flank where environmental conditions approach those of the interreef.

In the light of the interpretation offered it is concluded that in the Eason—Mayer No. 1 well (SE. $\frac{1}{4}$, NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, sec. 15), the greatest part of the Niagaran section above the Bainbridge consists of reef flank deposits. This view is supported by the nature of the dissociated and broken skeletal elements which form the major constituents of the limestones and dolomitic limestones and by the presence of inclined bedding planes and reef breccias. Only massive dolomites and dolomitic limestones can be regarded as marginal parts of the reef core proper. The coarse commonly pink crinoidal coquinas which form a blanketing layer across the top of the reef reflect the terminating phase of reef development and represent reworking and planation at the beginning of, and subsequent modification to, rough-water conditions.

The Eason—Mayer No. 1 well is marginally located with reference to the main body of the reef, as is indicated by the prevalence of reef flank deposits. The main development of the reef core is located more centrally with respect to the pool structure. Since the detrital mantle of the reef is comparatively thin, although variable in thickness, the structure on top of the Silurian seems to reflect roughly the major features of the reef. The highest part of the reef is located in the northeastern part of the pool where it is bordered by steeply dipping narrow flanks. The main axis of the reef body trends to the southwest where it is broad and platform-like. If the suggested interpretation of the reef structure is correct, it is evident that the localized structure centered at Eason—Mayer No. 1 well must be regarded as a vertical series of recurrent forereefs which developed and were in turn buried by debris from the main body of the reef.

A similar interpretation is suggested for the isolated small structure located northwest of the main reef body in the SE. $\frac{1}{4}$ sec. 8. The overlap of the pink detrital limestone on the interreef in this area is not sufficient to account for the local Silurian high, but the presence of a small forereef may account for the local structure.

In Ryan—Kisner No. 1 well (NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, SW. $\frac{1}{4}$, sec. 2), the dolomite which has been reported to underlie the pink detrital dolomite may represent a small forereef. The underlying Niagaran deposits, above the Bainbridge, are transitional in character between the reef and interreef lithologies. In the light of the interpretation offered, they appear to represent primarily reef-derived material of a selected grain size which was deposited in the adjacent interreef tract.

Future drilling between the three forereefs may determine whether they were isolated, as thought at present, or were interconnected in the form of a horseshoe-shaped barrier reef which in part surrounded the main reef.

BAINBRIDGE FORMATION

The typically developed Bainbridge comprises about 70 feet of red and green siltstones and shales with occasional thin beds of argillaceous limestone and about 60 feet of red to white massive coarsely crystalline limestone with occasional interbedded red or green shales and siltstones.

Those limestones in the upper portion are commonly light gray or green and finely to very finely crystalline. Of less common occurrence are coarsely crystalline white limestones which contain isolated fossil fragments that are in part replaced by red ferruginous material. The limestone in the

lower part of the formation consists of densely packed aggregates of pink and red, rarely white, medium- to coarse-grained crinoid fragments. Red ferruginous fossil fragments are especially common in these strata. The interstitial spaces of the fossil aggregates are filled with material which ranges in composition from clay to pure calcite.

The Bainbridge averages about 130 feet thick in the normal or interreef area but beneath the reef flank is only 55 feet thick, a figure which includes 10 feet of transition beds at the top.

The Bainbridge strata which underlie the reef and, to a variable extent the neighboring interreef area, are comparatively thin, ranging from 40 to 60 feet in thickness. Farther from the reef this facies thickens rapidly and reaches a maximum of about 170 feet. Beds contemporaneous with the upper portion of the red facies of the Bainbridge within the reef apparently consist of more or less typical reef deposits, and in the area immediately adjacent to the reef it consists of interreef deposits similar to those in the upper part of the Niagaran. In Eason—Mayer No. 1 well, beds contemporaneous with the upper part of the red Bainbridge consist of greenish-gray interreef deposits overlain by typical reef rock. It is possible that the thinning of the Bainbridge below the reef may be the result of squeeze and compaction caused by the load of the reef body. However, if so, it should be expected that typical Bainbridge would be developed uniformly in the whole interreef area up to the very edge of the reef. Further, if material had been squeezed out from beneath the reef the zone bordering the reef would have a greater thickness of Bainbridge than its normal interreef thickness. Maximum compaction of 20 feet may be involved but does not explain the thinning of the entire Niagaran in the interreef area. Lateral gradation from the typical facies of the upper red Bainbridge into contemporaneous beds of reef lithology is therefore suggested.

ALEXANDRIAN SERIES

The Alexandrian deposits are uniformly developed in the pool area and its environs. Two formations, the Sexton Creek and the Edgewood, are recognized on the basis of their lithologic similarity to and continuity with the surface exposures and on their stratigraphic relations.

Sexton Creek Formation.—The Sexton Creek formation comprises 20 to 40 feet of white to buff finely crystalline to lithographic limestones or dolomites. More or less spherical grains of glauconite occur commonly in the upper portions of the formation and help to distinguish it from the immediately overlying Bainbridge beds. With increase in depth, the glauconite becomes less common, and white, gray, or blue opaque chert makes its appearance.

Edgewood Formation.—The Edgewood formation in the Marine pool area consists of 10 feet of light brown to buff finely sucrose dolomite which in electric logs is characterized by a high self-potential. The formation appears to grade into the overlying Sexton Creek formation and in nearby areas can not be satisfactorily separated from it on the basis of gross lithology alone. Within the pool area it is distinguished by the absence of chert.

SILURIAN-DEVONIAN HISTORY

The broad features of Silurian and Devonian history may be summarized as follows.

Little is known at present about Alexandrian time beyond the fact that the sea which covered the area was first muddy, owing to reworking of Maquoketa material, and was later comparatively clear. Uniform sedimentation conditions apparently prevailed.

In early Niagaran time a depositional tract which extended across Illinois to the edge of the Michigan basin was influenced by the Ozark upland. Ozark-derived sediments contributed to the Bainbridge formation in southeastern Missouri and in southwestern Illinois as well as to the so-called Osgood[6] facies of the Joliet dolomite of

[6] Dunn, Paul, Silurian foraminifera of the Mississippian basin. Jour. Paleo., May 1942, p. 317.

northeastern Illinois. The Bainbridge sediments reflect a sea which was comparatively muddy from the fine clastics swept down from the Ozark upland. While similar sedimentation conditions still prevailed over most of the area, localized deviations promoted reef formation in the Marine area. Shortly thereafter, the Ozark-controlled sedimentation gave way gradually to the generalized offshore conditions which existed in most of Illinois in the normal or interreef tract. In contrast to the rough-water conditions in the reef area, still-water conditions prevailed in the interreef tract. The sea there was still comparatively muddy. Fluctuations in the amount of detrital material laid down are indicated by the rapidly shifting subfacies of the interreef realm. Within the immediate vicinity of the reef, the fine material derived from it was incorporated as a detrital fraction of the carbonate portion of the interreef sediments. In late Niagaran time, the reef building phase appears to have come to an abrupt end. The blanketing mantle of coquina indicates rough water conditions which accompanied cessation of reef building. The uniform thickness and character of the Wapsipinicon deposits indicate a nearly featureless Silurian surface across both reef and interreef areas. The fact that the reef was not truncated suggests that while rough-water sediments were slowly built up on the top of the dead reef, sediments must have accumulated rapidly in the interreef area. Probably the interreef sediments received a considerable part of the rough-water sediments which were within the carrying capacity of the turbulent water along the edge of the two facies realms. As a result, the interreef tract was built approximately to the level of the reef before the recession of the Silurian sea.

The Wapsipinicon sediments were deposited in a shallow sea. Following Wapsipinicon time the area was uplifted and the land surface was subjected to solution and development of fissures, after which the fissures were filled with clay and sand from an unknown source. This solution and subsequent filling of crevices extended down into the Silurian rocks.

The deposits laid down in Cedar Valley time reflect a very shallow sea with a muddy bottom which was above wave-base much of the time. The final deposits of the Devonian, the undifferentiated siltsones, indicate that the muddiness of the sea increased considerably whereas little chemical precipitation of carbonates took place.

OIL POTENTIALITIES AND MIGRATION

The producing area of the Marine pool coincides with the distribution of the reef facies. No producing wells nor oil shows have been reported from the surrounding interreef areas. The "pay zones" of the pool are nearly all located in the upper zone of pink derital limestone. In a limited number of producers the depth of production suggests that the pay is in the Wapsipinicon. Little is known about the petroleum possibilities of the reef core itself inasmuch as it is reached by none of the producers. Two feet of saturation in a thin zone of forereef facies were reported in the marginal Eason—Mayer No. 1 well. Testing to the base of the creviced zone within the main body of the reef is recommended, particularly after the decline of the present shallower production. This would require deepening to a depth of 50 to 100 feet below the top of the Silurian beds.

As suggested previously, it appears possible that the "Trenton" strata in the Marine pool area are structurally low. If this is true, a trap may be formed in the region of reversal of dip between the regional dip to the southeast and the margin of the pool where dips would be toward the center of the pool.

Core studies have produced few data which would lead to a proper interpretation of the accumulation of the oil. The fissures in the Silurian are suggestive as a means of oil migration. However, the fact that all of the fissures which have been recovered are tightly closed and packed with clay and sand would apparently restrict

migration to only those which were incompletely filled, or were filled only with sand. This may account for scattered Wapsipinicon production.

Some evidence was found in the core of the Rockhill—Pence-Mayer No. 1 well (NE. 1/4, NE. 1/4, sec. 16) for the development of zones of secondary porosity and permeability in the wall rock adjacent to the fissures. The pink detrital limestone, which is normally tight, is in this well soft and incoherent. The interstitial spaces of the coquina are in part open, or may be filled with white porous chalky carbonate material. The walls of the spaces are often thinly lined with minute crystals of calcite. In addition, some of the fossil elements show signs of solution. This porous zone was observed along the margins of a fissure and it seems probable that oil accumulation and migration may have been controlled by such porosity. These zones were probably developed at the time that the fissures were being subjected to solution. Zones of incompletely dissolved porous limestone were formed adjacent to the fissures, which after sand and clay filling had blocked the main crevices, were again subjected to ground water circulation which further increased their porosity and permeability. It seems probable, that during drilling the soft porous rocks of the "pay zone" usually disintegrate into an incoherent lime-sand which is recovered only in part or not at all. The erratic distribution of initial productions appears to be dependent more on the size and number of porous zones penetrated than upon structure.

The Wapsipinicon and Cedar Valley formations and the Devonian-Kinderhook shales have apparently acted as a caprock to prevent the vertical escape of oil from the pink detrital limestone.

The discovery of a Niagaran reef at Marine, far removed from the reef belt which fringes the Michigan basin and from the reef cluster in northwestern Illinois and Iowa, appears to be significant. The size of the Marine reef, at least as large as that of any other known Niagaran reef, suggests that the Niagaran deposits adjacent to the Ozark upland are potentially sites of other reefs, and as such have additional oil potentialities. It is not known at present whether the Marine reef is isolated or is a part of a reef belt. It seems at least possible that it may be connected by a series of reefs to the known area of reef development in the north.

At the present, it is not possible to distinguish by surficial methods those structures which represent Silurian reefs from those which are the result of deformation alone.

The pink crinoidal limestone which is confined to the reef area in the Marine pool and can be used as a guide to the distribution of the reef itself may not be similarly useful elsewhere. Depending upon the local history, a development of pink detrital limestone may be present over the top of the reef if the reef stopped growing while at or near wave base, or there may be an overlap of interreef facies on the reef wherever sediments accumulated faster than the growth of the reef. In the latter case, penetration of interreef beds below the Devonian does not necessarily imply the absence of a reef. It is suggested that detailed analysis, probably by insoluble residue methods, may produce criteria by which proximity to reefs can be recognized.

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